

Amendments to the Specification:

Delete the DISCLOSURE OF THE INVENTION section beginning at page 15, line 1 and ending at page 42, line 10 and replace it with the following BRIEF SUMMARY OF THE INVENTION section.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a direct-current power supply that suppresses the occurrence of excessive undershoot at the turning off of the bypass switch with its small circuit size and low conduction loss both maintained, thereby achieving high reliability.

One embodiment of a direct-current power supply according to the present invention includes a DC-DC converter, a converter control section, a bypass switch and a bypass control section. The DC-DC converter, by its switching operation, converts an input voltage applied from an external direct-current power supply into an output voltage equal to or higher than the input voltage, and applies the output voltage to an external load. The converter control section compares the output voltage with a desired voltage, and, based on their difference, controls the switching operation of the DC-DC converter. The bypass switch shorts between the input and output of the DC-DC converter. The bypass control section maintains the bypass switch in the ON state during non-operation of said DC-DC converter, and at start of the switching operation of the DC-DC converter, further maintains the bypass switch in the ON state for a predetermined time after the start of the switching operation.

Another embodiment of a direct-current power supply according to the present invention further includes a battery that supplies a predetermined battery voltage to the direct-current power supply.

Page 46, line 17: Replace the heading of the BEST MODE FOR CARRYING OUT THE INVENTION section with the heading title DETAILED DESCRIPTION OF THE INVENTION and with the text deleted above from the deleted DISCLOSURE OF THE INVENTION section beginning at page 15, line 2 and ending at page 42, line 10 as follows:

BEST MODE FOR CARRYING OUT THE INVENTION
DETAILED DESCRIPTION OF THE INVENTION

I. Overview of the Invention

An object of the present invention is to provide a direct-current power supply that suppresses the occurrence of excessive undershoot at the turning off of the bypass switch with its small circuit size and low conduction loss both maintained, thereby achieving high reliability.

A direct-current power supply according to the present invention comprises:
a DC-DC converter, by its switching operation, converting an input voltage applied from an external direct-current power supply into an output voltage equal to or higher than the input voltage, and applying the output voltage to an external load;
a converter control section comparing the output voltage of the DC-DC converter with a desired voltage, and, based on their difference, controlling the switching operation of the DC-DC converter;

a bypass switch shorting between the input and output of the DC-DC converter;
and

a bypass control section maintaining the bypass switch in the ON state during non-operation of the DC-DC converter, and at a start of the switching operation of the DC-DC converter, further maintaining the bypass switch in the ON state for a predetermined time from the start.

The above-described direct-current power supply according to the present invention is preferably installed in a battery-powered electronic apparatus. In other words, the above-described external direct-current power supply is preferably a battery, or alternatively, may be a virtual DC power to which an AC power entering from an AC power supply is rectified. On the other hand, the above-described external loads are preferably other modules in the battery-powered electronic apparatus equipped with the direct-current power supply. Alternatively, the loads may be other power systems, inverters, or converters.

The desired voltage is set, for example, to be equal to either a non-operating output lower limit (an allowable lower limit of the output voltage of the DC-DC converter during its non-operating period) or an operating output lower limit (an allowable lower limit of the output voltage of the DC-DC converter during its operating period), whichever is higher. The non-operating output lower limit is set, for example, higher than the allowable lower limit of the operating voltage of the external load by a predetermined margin (hereafter, a non-operating output margin). The non-operating output margin depends on the sum of the amount of fall of the input voltage during the starting-time of the converter control section and a margin against the drop of the output voltage caused by a predictable sharp rise of current in the external load, for example, a sharp rise due to the launching of an application on a notebook PC. The starting-time of the converter control section refers to the time required for the converter control section to change from the state at startup to the state ready for the switching control operation. The starting-time of the converter control section is mainly the time required for the converter control section to perform initialization. The initialization includes, for example, the activation of internal power sources for reference voltages and the initialization of latch circuits. The operating output lower limit is set, for example, higher than an allowable lower limit of the operating voltage of the external load by a predetermined margin (hereafter, an operating output margin). The operating output margin depends on the sum of a ripple voltage included in the output voltage during the operating period of the DC-DC converter and a margin against the drop of the output voltage caused by a predictable sharp rise of current in the external load.

The above-described direct-current power supply according to the present invention comprises the DC-DC converter and the bypass switch. When the input voltage is sufficiently higher than the desired voltage, the converter control section maintains the DC-DC converter under non-operating conditions. The bypass control section then maintains the bypass switch in the ON state. Thereby, the output voltage is maintained lower than the input voltage by the voltage drop across the parallel connection of the DC-DC converter and the bypass switch. Conversely, when the input voltage is lower than the desired voltage, the converter control section starts the DC-DC

converter. The bypass control section then maintains the bypass switch in the OFF state. The output voltage rises beyond the input voltage due to the boost operation of the DC-DC converter, and is maintained substantially equal to the desired voltage. Thus, the above-described direct-current power supply can maintain the output voltage, at the lowest, substantially equal to the desired voltage when the input voltage greatly varies; for example, when the battery voltage falls at the last stage of its discharge or when the direct voltage sent from the rectifier pulsates. Especially when the external power supply is batteries, the above-described direct-current power supply can maintain the output voltage substantially equal to the desired voltage until the instant when the batteries reach the substantially complete discharge state. As a result, the use efficiency of the battery capacity improves.

A battery voltage preferably falls below the above-described desired voltage in the middle stages of the discharge of the battery, in a battery-powered electronic apparatus equipped with the above-described direct-current power supply according to the present invention. In particular, new-model lithium ion rechargeable batteries with energy density higher than that of current lithium ion rechargeable batteries have comparatively low discharge end voltages and discharge curves with comparatively steep gradients. Then, the above-described direct-current power supply according to the present invention reliably maintains the output voltage, at the lowest, to be equal to the desired voltage. Accordingly, the above-described direct-current power supply according to the present invention has advantages in the use efficiency of the battery capacity, in particular, in the use of the new-model lithium ion rechargeable batteries.

The battery-powered electronic apparatuses equipped with the above-described direct-current power supplies according to the present invention preferably comprise a wireless transmitter section sending a signal by radio waves. In other words, the battery-powered electronic apparatuses, such as cellular phones, have wireless communications capabilities. The wireless transmitter section more preferably comprises a power amplifier section amplifying a signal to be sent under the application of the output voltage of the DC-DC converter. Generally in the power amplifier section, the stepping down of the operating voltage is difficult, and accordingly, its desired voltage is

comparatively high. Therefore, the battery voltage falls below the desired voltage in the middle stages of the discharge of the battery. Then, the above-described direct-current power supply according to the present invention reliably maintains the output voltage, at the lowest, to be equal to the desired voltage. Accordingly, the above-described direct-current power supply according to the present invention has advantages in the use efficiency of the battery capacity, in particular, for the battery-powered electronic apparatuses having wireless communications capabilities.

In the above-described direct-current power supply according to the present invention, the bypass control section maintains the bypass switch in the ON state during the non-operating period of the DC-DC converter. Then, the current is split into two branches between the input and output of the above-described direct-current power supply. The one branch flows through the DC-DC converter and the other branch flows through the bypass switch. Accordingly, the turning-on of the bypass switch reduces the resistance between the input and output of the above-described direct-current power supply. Thus, the above-described direct-current power supply reduces the voltage drop (non-operating voltage drop) between its input and output during the non-operating period of the DC-DC converter. As a result, the conduction loss during the non-operating period of the DC-DC converter is suppressed. When the external direct-current power-supply is a battery, in particular, the use efficiency of the battery capacity is improved.

The bypass control section further maintains the bypass switch in the ON state for a predetermined time from the start of the switching operation of the DC-DC converter, and then turns the bypass switch off, in the above-described direct-current power supply according to the present invention, in sharp contrast to the conventional direct-current power supplies. The predetermined time is set, at the shortest, to be equal to the starting-time of the converter control section. Preferably, the output voltage rises due to the boost operation of the DC-DC converter, and until the instant when the output voltage meets the input voltage, the bypass control section maintains the bypass switch in the ON state. Accordingly, when the DC-DC converter starts the switching operation, the difference between the input and output voltages is suppressed to a level equal to or lower than the non-operating voltage drop. In particular, no excessive undershoots occur on the output

voltage. Thus, the above-described direct-current power supply according to the present invention has high reliability for the stability of the output voltage. When the external load is an electronic device, in particular, the electronic device avoids a sudden abort due to an abrupt drop of the operating voltage. More preferably, the bypass control section turns the bypass switch off under the conditions where the current passing through the bypass switch (hereafter, the bypass current) is substantially equal to zero. Thereby, no switching losses occur. Accordingly, the above-described direct-current power supply according to the present invention suppresses its power consumption. As a result, when the external direct-current power supply is, in particular, a battery, the use efficiency of the battery capacity is improved.

The following two modes are in particular preferable as concrete means of further maintaining the bypass switch in the ON state for a predetermined time from the start of the switching operation of the DC-DC converter. In a first mode, the bypass control section determines the turning-on/off of the bypass switch based on the changes in state between the input and output of the DC-DC converter due to its boost operation. In a second mode, the bypass control section delays the starting signal for the converter control section by a predetermined delay time, and sends it as an off signal for the bypass switch.

In the first mode, the bypass control section:
compares voltages between the input and output of the DC-DC converter,
turns the bypass switch on when the input voltage is higher than the output
voltage, and
turns the bypass switch off when the input voltage is lower than the output
voltage.

Preferably, the bypass control section includes a comparator. The comparator produces a logical level in response to the relative levels between the input and output voltages of the DC-DC converter. Furthermore, its H and L levels are sent to the bypass switch as on and off signals, respectively, or vice versa. In the first mode, the bypass switch maintains the ON state from the start of the switching operation of the DC-DC converter until the instant when the input voltage substantially meets the output voltage.

Thereby, the difference between the input and output voltages is suppressed to be equal to or lower than the non-operating voltage drop during the period. In particular, no excessive undershoots occur on the output voltage. Furthermore, no switching loss occurs since the bypass switch is turned off under the conditions where the bypass current is substantially equal to zero.

The above-described bypass control section compares the voltages between the input and output of the DC-DC converter, and determines the turning-on and off of the bypass switch. The bypass control section may in addition, detect the bypass current and, based on its amount or direction, determine the turning-on and off of the bypass switch. After the DC-DC converter starts its switching operation, preferably, the bypass control section turns the bypass switch off at the instant when the bypass current substantially falls to zero. The bypass control section may turn the bypass switch off at the instant when the direction of the bypass current is reversed. The bypass control section may further detect the output current of the DC-DC converter and the output current to the external load (hereafter, a load current), and based on those detected values, determine the turning-on and off of the bypass switch. For example, the bypass control section may turn the bypass switch off at the instant when the load current nearly meets the output current of the DC-DC converter.

In the second mode,

the above-described direct-current power supply comprises a start control section sending a predetermined start signal to the converter control section based on one or both of the input and output voltages;

the converter control section during non-operation starts upon receipt of the start signal; and

the bypass control section includes:

(a) a signal delay section holding the start signal for a predetermined delay time from the instant of the receipt, and

(b) a switch driving section maintaining the bypass switch in the ON state until the receipt of the start signal from the signal delay section, and turning off the bypass switch at the receipt of the start signal.

Here, the delay time is set, at the shortest, to be substantially equal to the starting-time of the converter control section, and preferably, substantially equal to the constant value estimated as the duration from the start of the converter control section until the instant of the agreement between the input and output voltages.

In the second mode, the signal delay section delays the sending of the start signal to the switch driving section by the above-described delay time from the occurrence of the start signal. Thereby, the bypass switch further maintains the ON state for, at the shortest, the starting-time of the converter control section after the start of the converter control section. Accordingly, the difference between the input and output voltages is maintained to be equal to or lower than the non-operating voltage drop during, at the shortest, the starting-time of the converter control section. In particular, no excessive undershoots occur on the output voltage. Furthermore, the instant of the turning-off of the bypass switch is sufficiently immediate after the instant of the agreement between the input and output voltages at the above-described desirable setting of the delay time. Accordingly, the switching loss is suppressed since the bypass switch is turned off under the conditions where the bypass current is small enough. Here, the bypass control section may monitor the bypass current after the receipt of the start signal and, based on the amount of the current, adjust the delay time. According to the adjustment, the bypass switch is turned off, when the bypass current substantially falls to zero. Thereby, the switching losses of the bypass switch at the turning-off are reduced.

In the second mode, furthermore,
the start control section may send a predetermined stop signal to the converter control section, based on the input voltage of the DC-DC converter;
the converter control section during operation may stop upon the receipt of the stop signal; and
in the bypass control section,
(a) the signal delay section may hold the stop signal for a predetermined delay time from the instant of the receipt, and
(b) the switch driving section may maintain the bypass switch in the OFF state until the receipt of the stop signal sent from the signal delay section, and turn on the

bypass switch at the receipt of the stop signal. Here, the delay time may be substantially equal to the delay time for the start signal. When the external power supply is a battery, for example, the repetition of its charge and discharge causes the input voltage to repeat fall and rise alternately. When the input voltage rises in the boost operation of the DC-DC converter and, for example, the ratio of the desired voltage to the input voltage reaches a predetermined level, the start control section sends the stop signal and then, the converter control section and the DC-DC converter stop. On the other hand, the bypass control section further maintains the bypass switch in the OFF state by the above-described delay time even after the stop of the DC-DC converter, owing to the delay of the stop signal. Thereby, the bypass switch is turned on when the difference between the input and output voltages is fully reduced and the bypass current fully falls. As a result, the switching losses are reduced for the turning-on of the bypass switch.

The above-described direct-current power supply according to the present invention may comprise an input voltage detecting section comparing the input voltage with a start input voltage;

the converter control section may, based on the output of the input voltage detecting section,

(a) maintain the DC-DC converter in non-operation during the period when the input voltage is higher than the start input voltage, and

(b) cause the DC-DC converter to start the switching operation at the detection of the fall of the input voltage to the start input voltage. Here, the start input voltage is set as the input voltage at the start of the converter control section. According this configuration, the converter control section may maintain its stop conditions during the period when the input voltage is higher than the start input voltage. Thereby, the power consumption for the converter control section is reduced in the period.

For example, the start input voltage is set, at the lowest, to be equal to the sum of the desired voltage and a voltage drop upper limit (or an allowable upper limit of the non-operating voltage drop). Here, the voltage drop upper limit depends on the product of the resistance across the direct-current power supply during the ON period of the bypass

switch and the allowable upper limit of the load current. The desired voltage is equal to or beyond the non-operating output lower limit. Accordingly, the starting input voltage is equal to or beyond the sum of the non-operating output lower limit and the voltage drop upper limit. Therefore, when the input voltage falls to the start input voltage, the output voltage is equal to or beyond the non-operating output lower limit. Thus, the output voltage is maintained higher enough than the allowable lower limit of the operating voltage of the external load during the starting-time of the converter control section.

The start input voltage may be additionally set, at the lowest, to be equal to the sum of the non-operating output lower limit and the voltage drop upper limit. At that time, the start input voltage may be lower than the desired voltage. The DC-DC converters, in general, include a DC-DC converter having a lower limit of its step-up ratio higher than one. Hereafter, a lowest step-up ratio refers to the lower limit of the step-up ratio. In the above-described direct-current power supply according to the present invention, the desired voltage is set, at the lowest, to be equal to either the lowest step-up ratio times as high as the start input voltage or the operating output lower limit, whichever is higher, when the DC-DC converter has the lowest step-up ratio higher than one. In that case, the ratio of the desired voltage to the input voltage is higher than the lowest step-up ratio at the start of the converter control section. Therefore, the converter control section can control the DC-DC converter with stability so that the output voltage does not greatly exceed the desired voltage. As a result, the DC-DC converter operates with stability.

The above-described direct-current power supply according to the present invention may further comprise:

an input voltage detecting section comparing the input voltage with a stop input voltage;

an output voltage detecting section comparing the output voltage with a start output voltage; and

a start control section,

based on the output of the output voltage detecting section,

(a) maintaining the converter control section in non-operation during the period when the output voltage is higher than the start output voltage, and
(b) causing the converter control section to start at the detection of the fall of the output voltage to the start output voltage, and
based on the output of the input voltage detecting section,

(c) maintaining the converter control section in operation during the period when the input voltage is lower than the stop input voltage, and
(d) causing the converter control section to stop at the detection of the rise of the input voltage to the stop input voltage.

Here, the start output voltage is set as the output voltage at the start of the converter control section. The stop input voltage is set as the input voltage at the stop of the converter control section under operating conditions.

For example, the start output voltage is set, at the lowest, to be equal to the non-operating output lower limit. At that time, the start output voltage may be lower than the desired voltage. Especially when the DC-DC converter has the lowest step-up ratio higher than one, the desired voltage is set, at the lowest, to be equal to either the lowest step-up ratio of the DC-DC converter multiplied by the sum of the start output voltage and the voltage drop upper limit, or the operating output lower limit, whichever is higher. At the start of the converter control section, the output voltage is substantially equal to the start output voltage, and the input voltage is equal to or below the sum of the output voltage and the voltage drop upper limit. Accordingly, the ratio of the desired voltage to the input voltage is equal to or beyond the lowest step-up ratio. Therefore, the converter control section can control the DC-DC converter with stability so that the output voltage does not substantially exceed the desired voltage. As a result, the DC-DC converter operates with stability.

The stop input voltage is, for example, set to be at the lowest equal to the sum of the start output voltage and the voltage drop upper limit. Furthermore, when the DC-DC converter has a lowest step-up ratio higher than one, the stop input voltage is set to be equal to or lower than the desired voltage divided by the lowest step-up ratio. In other

words, the ratio of the desired voltage to the stop input voltage is equal to or beyond the lowest step-up ratio. When the external power supply is a battery, for example, the input voltage repeatedly falls and rises alternately due to the repetition of the charge and discharge. The ratio of the output voltage to the input voltage falls when the input voltage rises during the boost operation of the DC-DC converter, since the output voltage is maintained substantially equal to be the desired voltage. When the input voltage meets the stop input voltage, the converter control section stops, and then the DC-DC converter stops. At that time, the ratio of the output voltage to the input voltage is equal to or beyond the lowest step-up ratio. Thus, the DC-DC converter stops with stability at the rise of the input voltage.

After the stop of the DC-DC converter, the output voltage falls from the desired voltage, and meets the input voltage. At that time, the bypass control section turns the bypass switch on. Thereby, the output voltage is maintained at the level lower than the input voltage by the non-operating voltage drop. Here, the output voltage is maintained to be equal to or beyond the start output voltage since the input voltage is equal to or beyond the stop input voltage. Thus, when the input voltage repeatedly falls and rises alternately, the output voltage is maintained sufficiently higher than the allowable lower limit of the operating voltage of the external load.

In the above-described direct-current power supply according to the present invention, based on the outputs of the input and output voltage detecting sections, the start control section may

(a) maintain the converter control section in non-operation during the period when the input voltage is higher than the stop input voltage and the output voltage is higher than the start output voltage, and

(b) cause the converter control section to start when the input voltage falls below the stop input voltage and the fall of the output voltage to the start output voltage is detected.

When power is provided for the above-described direct-current power supply by the connection with the battery in a fully charged condition, for example, the input voltage is higher than the stop input voltage, and the output voltage is lower than the start

output voltage. The above-described start control section accurately judges the start of the converter control section based on not only the output voltage but also the input voltage. In particular, when the input voltage is lower than the stop input voltage and the output voltage is lower than the start output voltage, the converter control section starts. Accordingly, the mis-operation of the DC-DC converter is avoided at power-on, and accordingly, the occurrence of excessive output voltage is prevented.

In the above-described direct-current power supply according to the present invention,

the DC-DC converter may have the ability of buck operation converting the input voltage into the output voltage equal to or lower than the input voltage, in addition to the ability of boost operation converting the input voltage into the output voltage equal to or higher than the input voltage;

the converter control section, based on the difference between the output voltage and the desired voltage, may cause the DC-DC converter to perform one of the buck and boost operations, and maintain the DC-DC converter in non-operation; and

at the start of the boost operation of the DC-DC converter, the bypass control section may further maintain the bypass switch in the ON state for a predetermined time from the instant of the start.

In the configuration, the desired voltage is set, for example, to be at the lowest equal to either the output lower limit at the buck operation or the output lower limit at the boost operation of the DC-DC converter, whichever is higher. The operating output lower limit is set, for example, higher than the allowable lower limit of the operating voltage of the external load by an operating output margin for each of the buck and boost operations. The operating output margin depends on the sum of a ripple voltage included in the output voltage during the operating period and a margin against drops of the output voltage caused by predictable, rapid increases in the current in the external load.

When the input voltage is higher than the desired voltage, the converter control section causes the DC-DC converter to perform the buck operation. The bypass control section then maintains the bypass switch in the OFF state. The output voltage falls due to the buck operation of the DC-DC converter, and is maintained substantially equal to the

desired voltage. Conversely, when the input voltage is lower than the desired voltage, the converter control section causes the DC-DC converter to perform the boost operation. The bypass control section then maintains the bypass switch in the OFF state. The output voltage rises due to the boost operation of the DC-DC converter, and is maintained substantially equal to the desired voltage. Thus, when the input voltage greatly varies, the above-described direct-current power supply according to the present invention can maintain the output voltage substantially equal to the desired voltage throughout the variation period of the input voltage. Especially when the external power supply is a battery, the output voltage is maintained substantially equal to the desired voltage throughout the discharge period of the battery. As a result, the use efficiency of the battery capacity further improves.

When the input voltage fluctuates in the vicinity of the desired voltage, the converter control section maintains the DC-DC converter in non-operation. The bypass control section then maintains the bypass switch in the ON state. Thereby, the output voltage is maintained lower than the input voltage by the non-operating voltage drop. In addition, during the non-operating period of the DC-DC converter, the current is split into two branches between the input and output of the direct-current power supply, and the one branch passes through the DC-DC converter and the other branch passes through the bypass switch. Accordingly, the resistance between the input and output of the direct-current power supply is reduced due to the turning-on of the bypass switch. Thus, the above-described direct-current power supply according to the present invention suppresses the non-operating voltage drop. As a result, the conduction loss of the DC-DC converter is suppressed during the non-operating period. Especially when the external power supply is a battery, the use efficiency of the battery capacity improves.

The bypass switch is maintained in the ON state, especially at the start of the boost operation of the DC-DC converter. Thereby, the difference between the input and output voltages is maintained equal to or less than the non-operating voltage drop during the non-operating period of the DC-DC converter. In particular, no excessive undershoots occur on the output voltage. Furthermore, no switching loss is produced since the bypass switch is turned off under the conditions where the bypass current is

substantially equal to zero. Thus, the above-described direct-current power supply according to the present invention has high reliability for the stability of the output voltage.

Any of the direct-current power supplies according to the present invention preferably comprises a synchronous rectifier section performing rectification during operation of the DC-DC converter in synchronization with its switching operation, and maintaining the ON state during non-operation of the DC-DC converter. Especially when the DC-DC converter can perform the buck operation in addition to the boost operation, the synchronous rectifier section performs rectification during the boost operation of the DC-DC converter in synchronization with its switching operation, and maintains the ON state during the non-operation of the DC-DC converter. Generally, the synchronous rectifier section produces conduction losses lower than those produced by a diode. Accordingly, the DC-DC converter produces low conduction losses in this direct-current power supply.

The above-described direct-current power supply according to the present invention preferably comprises a step-up chopper, or the boost converter with an inductor, as the DC-DC converter. Furthermore, the direct-current power supply may comprise a buck/boost converter with an inductor as the DC-DC converter having the ability of the buck operation. Alternatively, the DC-DC converter may be, for example, a buck/boost converter such as a Cuk, Zeta, or Sepic converter. The DC-DC converter may further adopt a charge pump with a capacitor and a switch.

The above-described direct-current power supply according to the present invention, further preferably, comprises a stop switch. The stop switch, under the on-off control of the external load, interrupts either an input current from the external direct-current power supply or an output current to the external load. Especially when the DC-DC converter includes an output smoothing capacitor connected in parallel with the external load and a node near the external load between the DC-DC converter and the bypass switch is placed closer the external direct-current power supply than the output smoothing capacitor, the stop switch is preferably connected between the node and the output smoothing capacitor. Alternatively, the stop switch may be connected at a point

nearer the external direct-current power supply than the node near the external direct-current power supply between the DC-DC converter and the bypass switch. When the external load shifts to its suspend state, for example, the external load turns the stop switch off. Thereby, the output current of the DC-DC converter and the bypass current are both interrupted, and in other words, the load current is cut off. Thus, the external load cuts the power from the direct-current power supply. As a result, no power is provided to the external load and therefore, power consumption by the external load is suppressed. Especially when the external power supply is a battery, its use efficiency improves.

When the above-described direct-current power supply according to the present invention includes the above-described stop switch, the bypass control section may further detect the output current of the DC-DC converter and the ON voltage of the stop switch, and based on those detected values, determine the on/off states of the bypass switch. For example, the bypass control section may detect the load current from the ON voltage of the stop switch, and may turn the bypass switch off at the instant when the load current nearly meet the output current of the DC-DC converter.

As described above, the bypass control section further maintains the bypass switch in the ON state for a predetermined time from the instant of the start of the switching operation by the DC-DC converter in the direct-current power supply according to the present invention, in contrast to conventional direct-current power supplies. The predetermined time is in particular equivalent to the sum of the starting-time of the converter control section and the recovery time to the desired voltage of the output voltage. Accordingly, at the start of the switching operation by the DC-DC converter, the difference between the input and output voltages is suppressed to be equal to or below the non-operating voltage drop. In particular, no excessive undershoots occur on the output voltage. Thus, the direct-current power supply according to the present invention has high reliability for the stability of the output voltage. Especially when the external load is an electronic device, a sudden abort of the electronic device due to an abrupt drop of the operating voltage is avoided.

While the novel features of the invention are set forth particularly in the appended claims, the invention, both as to organization and content, will be better understood and appreciated, along with other objects and features thereof, from the following detailed description taken in conjunction with the drawings.

II. Detailed Disclosure